Emission Analysis Approach for EPA's Multi-scale Motor Vehicle & Equipment Emission System (MOVES)

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U.S. EPA

Office of Transportation & Air Quality

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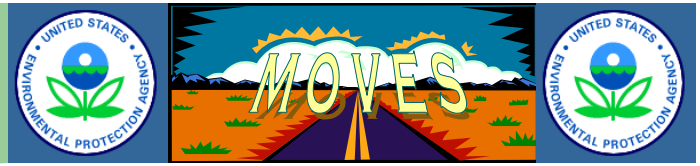


Acknowledgements

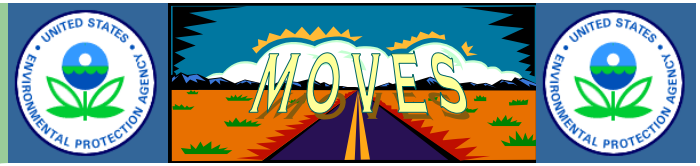
- Connie Hart, Dave Brzezinski, Bob Giannelli, Chad Bailey (EPA)
- Ed Nam (Ford Motor Company)

MOVES Documentation Available

- **Draft MOVES Design and Implementation Plan**
- **Draft MOVES GHG Emission Analysis Plan**
- **On-Board "Shootout" Reports**
  - Test Program Report (Sensors, Inc.)
  - Contractor Analysis Reports (UC Riverside, NCSU, ENVIRON)
  - Overview and Results (EPA)
- **Modal emission analysis (NCSU)**
- **Proof-Of-Concept Physical Model (Ed Nam)**
- **Analysis of CO_2/CH_4 Emissions (ERG)**
- **Mobile Source Observation Database update (ERG)**
- **www.epa.gov\otaq\ngm.htm or newgen@epa.gov**

Not Covered Today…

- Background (CRC 2001, 2002)
- Multi-scale design framework
- MOVES emission processes
- Vehicle characterization
- Emission adjustments
- Advanced technologies
- Fleet and activity-related analyses

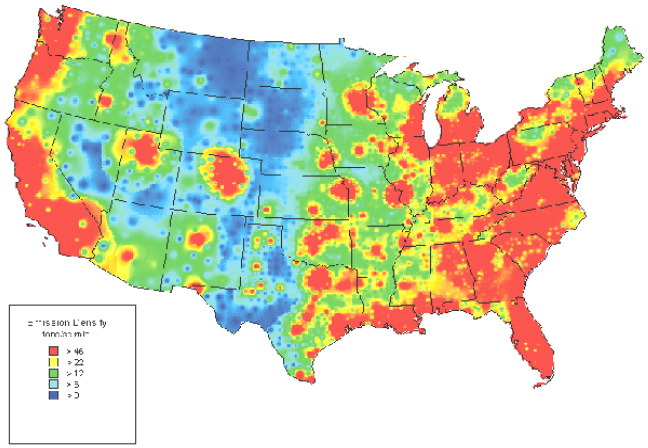


MOVES Implementation Plan

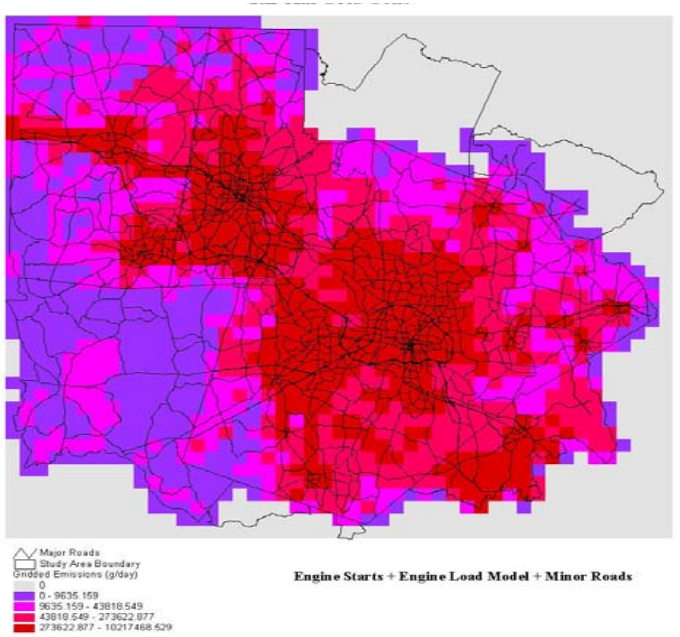
- **MOVES GHG (on-road)**
  - Draft release: Early 2004
    - Fuel consumption, CO_2, CH_4, N_2O inventories 1999 forward
    - Would include life cycle and policy evaluation components
- **Full on-road implementation: Fall 2005**
  - Add HC, CO, NOx, Toxics, PM, NH_3, SO_2
  - Multi-scale analysis capability
  - Will replace MOBILE6
- **Off-Road: 2006**
  - Will replace NONROAD

MOVES Analysis Scales

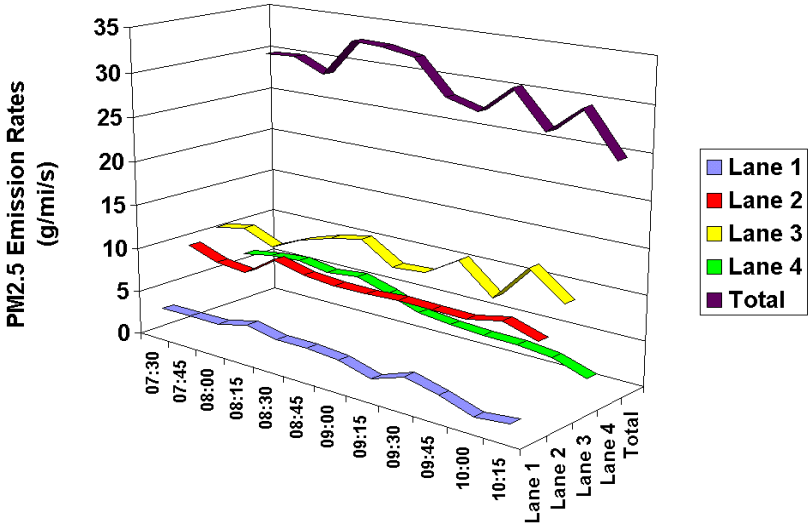
Macroscale



Mesoscale



Microscale



Sources: EPA OAQPS, ORD

MOVES Software Framework

- Language: Java®
- Database-driven structure
  - Open-source relational database (MySQL)
  - Enables modularity, easy updates with new data
- Graphical user interface or batch mode
- Designed for multiple-computer processing
- Output reporting and visualization

Emission Analysis Background

- **Analysis of Factors Important for CO_2/CH_4 (ERG)**
  - Preliminary analysis to determine most important variables
- **On-Board Shootout (UCR, NCSU, ENVIRON, EPA)**
  - Evaluation different methods of using on-board (PEMS) data for multi-scale inventory modeling
- **Modal Binning Proof-of-Concept (NCSU)**
  - Analysis of modal binning issues using dyno, PEMS, RSD and I/M data
- **PERE: Physical Emission Rate Estimator (Ed Nam)**
  - Develop model based on physical principles which could be used to populate emission rate database where test data is lacking

Modal Binning

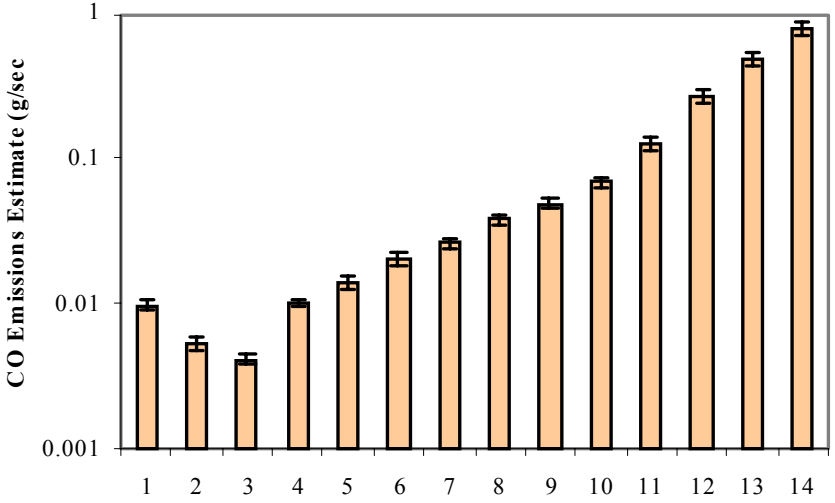
- **Group activity and emissions into "Bins"**
  - Shootout and NCSU work focused on Vehicle Specific Power (VSP)
    - Accounts for speed, acceleration, grade, road load
- **Any driving pattern can be modeled based on distribution of time spent in bins**
  - Adds major flexibility compared to MOBILE
- **Provides common emission rates for macroscale, mesoscale, microscale**

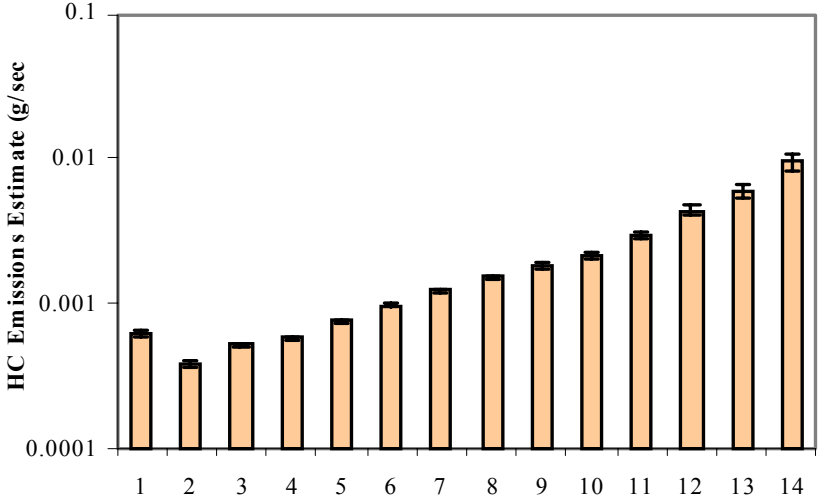
Vehicle Specific Power (VSP)

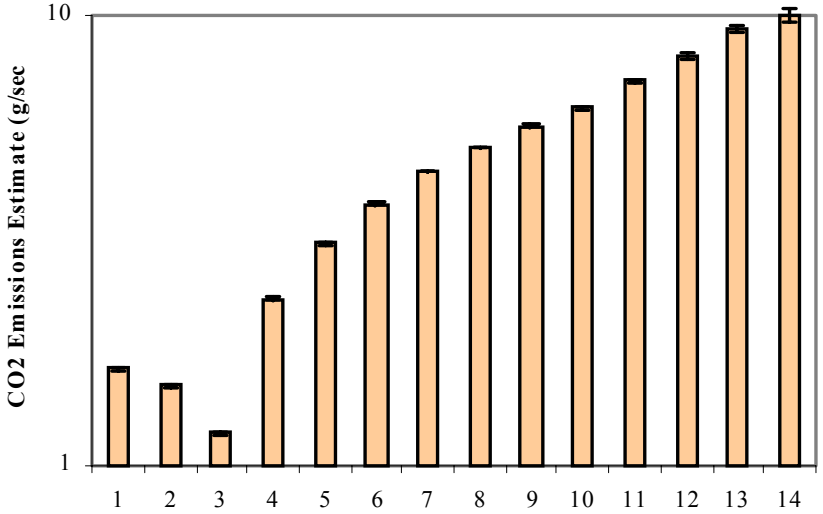
- **Jiménez-Palacios (MIT, 1999)**
  - VSP = $v*(a*(1+\varepsilon) + g*grade + g*C_R) + 0.5\rho*C_D*A*v^3/m$
  - Applied generic coefficients for light-duty:
    - VSP (kW/ton) = $v*(a*(1.1) + g*grade + 0.132) + 0.0003*v^3$
  - Can be applied to heavy-duty as well

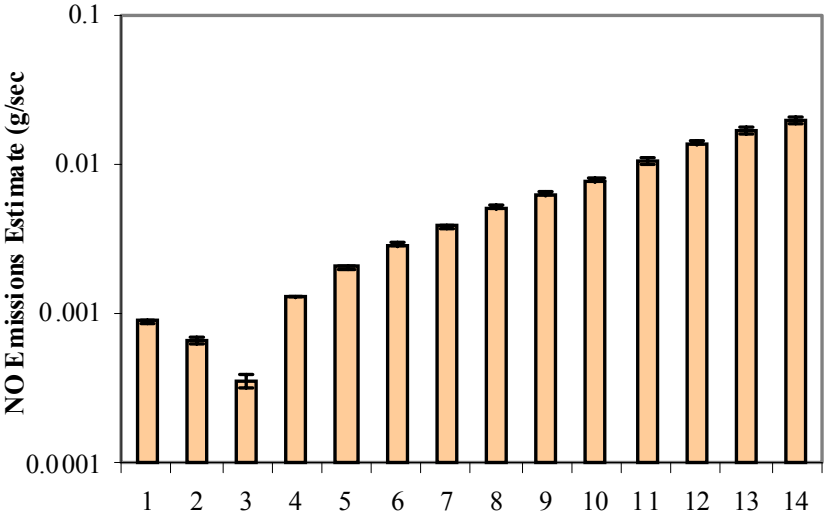
- **CMEM / PERE**
  - VSP = $[A*v + B*v^2 + C*v^3 + m*v*(a + g*grade))]/m$
  - Use road load (A/B/C) coefficients:
    - Light-duty: derived from dyno hp target (IM240 lookup)
    - Heavy-duty: available estimates of C_r, $C_{d,}$ Frontal Area

Emissions by 14 VSP Bins Recommended by NCSU



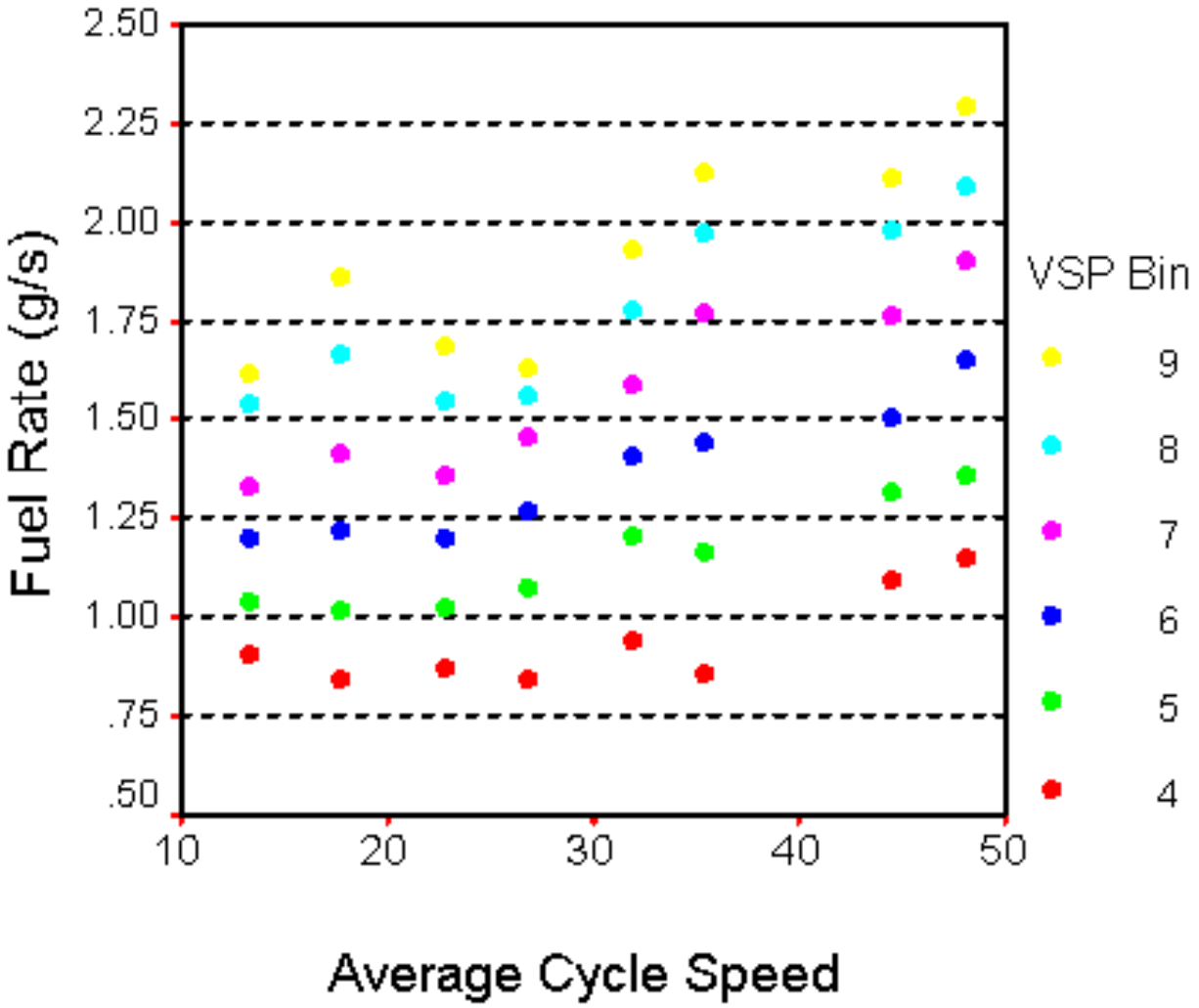






Fuel Rate By VSP Bin and Average Cycle Speed

ARB UCC Dataset (26 1983-1998 LDV/LDTs)



Supplementing VSP

- **VSP by itself does not explain variability observed across full range of driving**
- **MOVES GHG Emission Analysis Plan proposed binning by average speed and VSP**
- **Limitations of binning by average speed:**
  - Doesn't address physical nature of bias
  - Requires knowing average speed of driving pattern, rather than relying on instantaneous driving only

New Concept: Engine Specific Power (ESP)

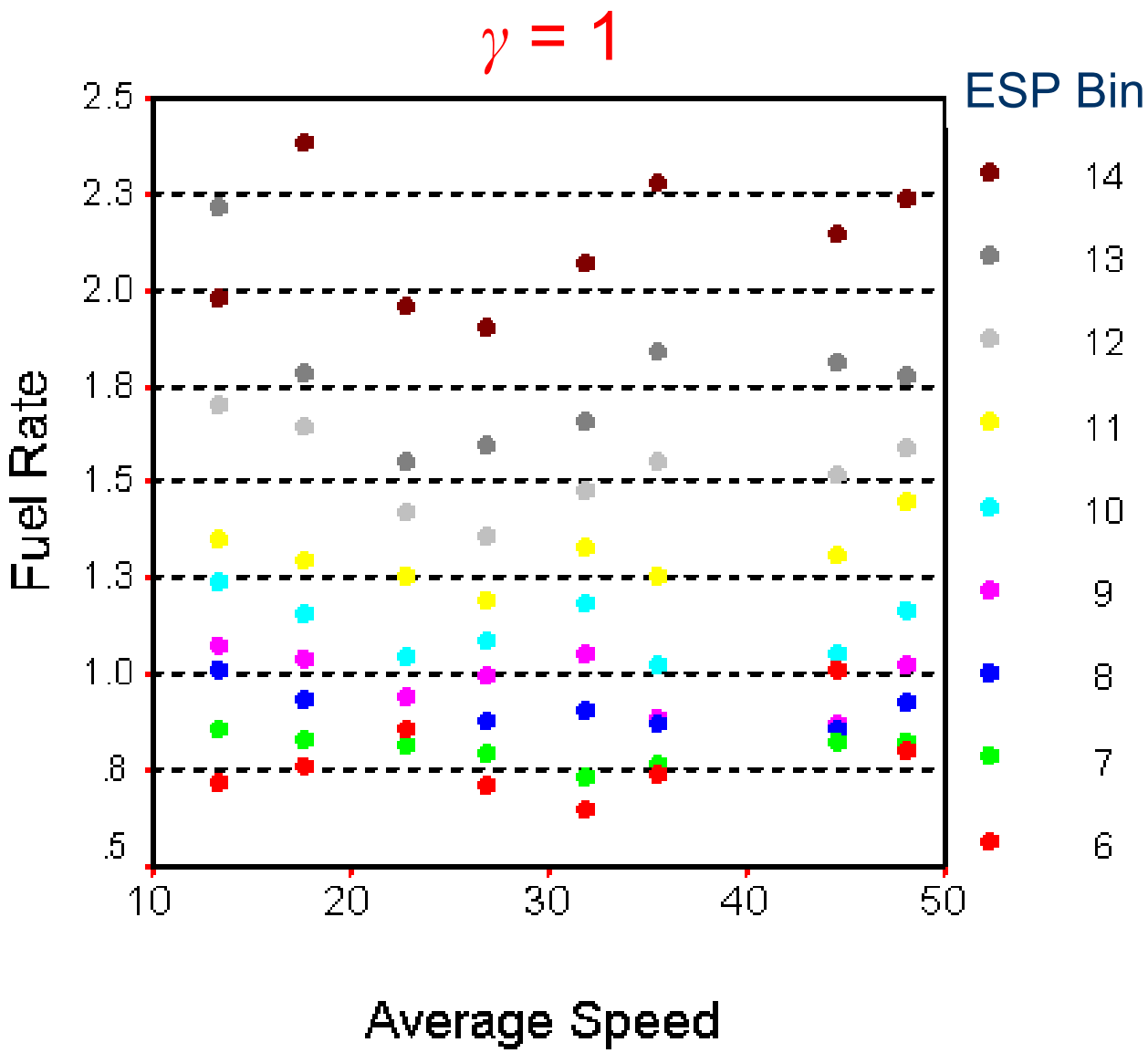
- **VSP doesn't capture engine losses, e.g. friction, which affect fuel consumption**
- **ESP proposed by Nam:**
  - Adds surrogate engine loss term
  - ESP = VSP + γ*Speed
  - γ = "engine friction constant"
    - Accounts for K, RPM/speed, engine displacement
    - Enables ESP to be calculated knowing only VSP and instantaneous speed
- **Can use same 14 bins defined by NCSU**

Estimating γ

- **Physical approach**
  - Approximate engine friction term KNV_d (Ross, CMEM) with simplified estimates of RPM/speed, displacement/mass, engine friction coefficient
- **Empirical approach**
  - γ*Speed = ESP – VSP = (Fuel * LHV * η / m) – VSP
- **Calibration approach**
  - Treat γ as “error term” to account for unexplained bias

Fuel Rate By ESP Bin and Average Cycle Speed

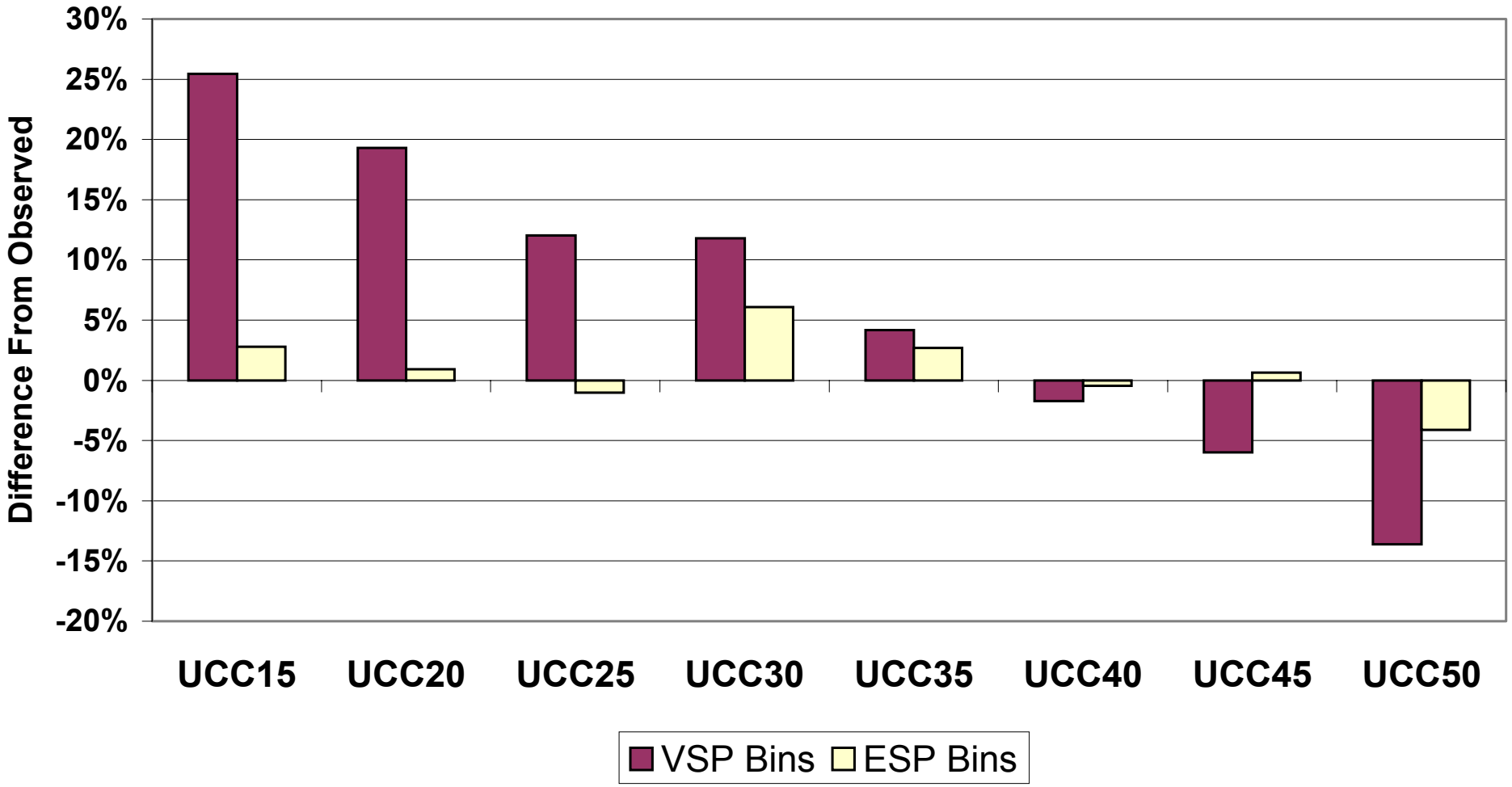
ARB UCC Dataset (26 1983-1998 LDV/LDTs)



Fuel Consumption Validation

ARB UCC Dataset (26 1983-1998 LDV/LDTs)

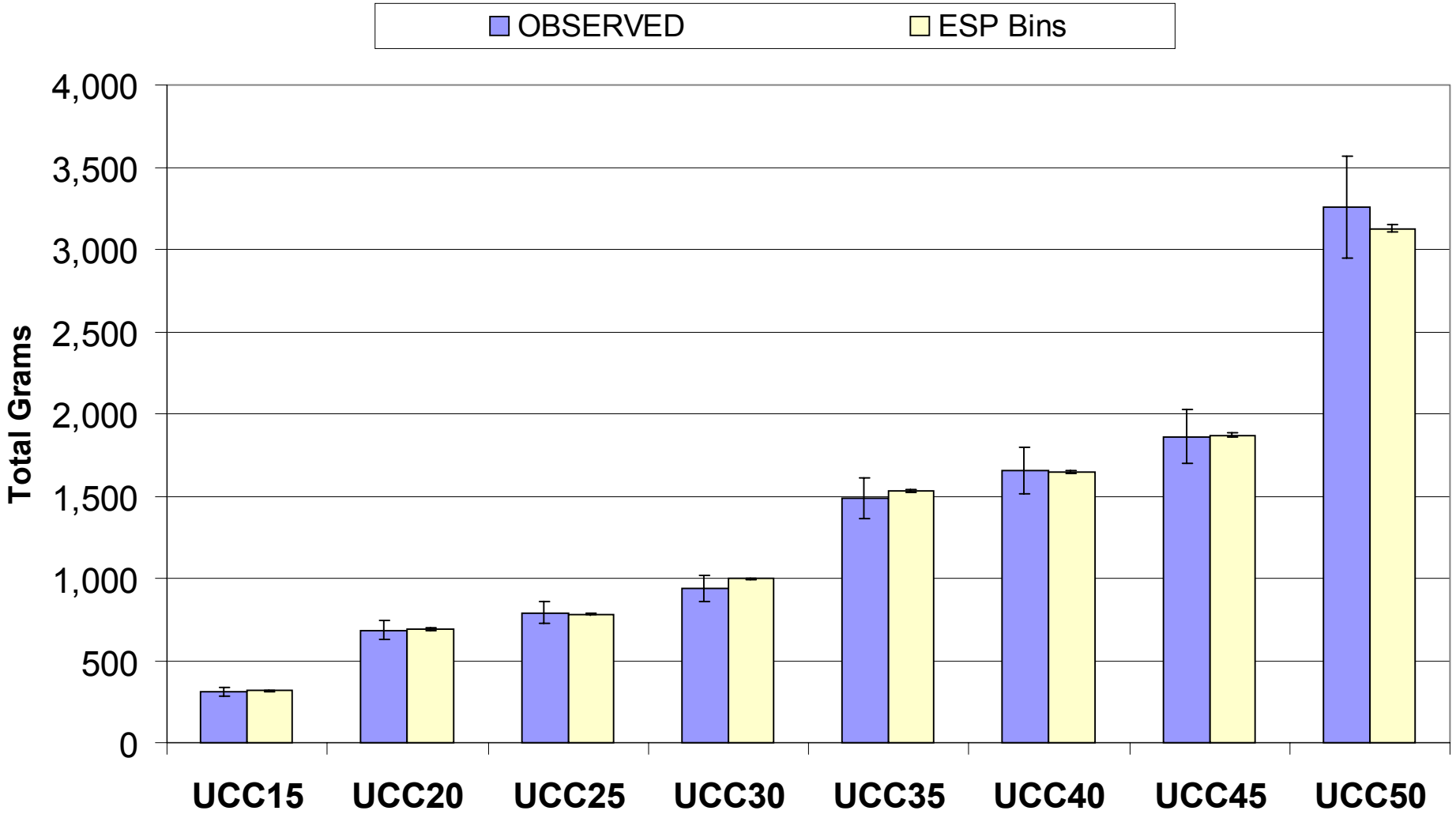
Each Cycle Predicted Independently Based on Binned Fuel Consumption Rates From The Other 7 Cycles



Fuel Consumption Validation

Total Fuel Consumption Per Cycle, Averaged Across Vehicles

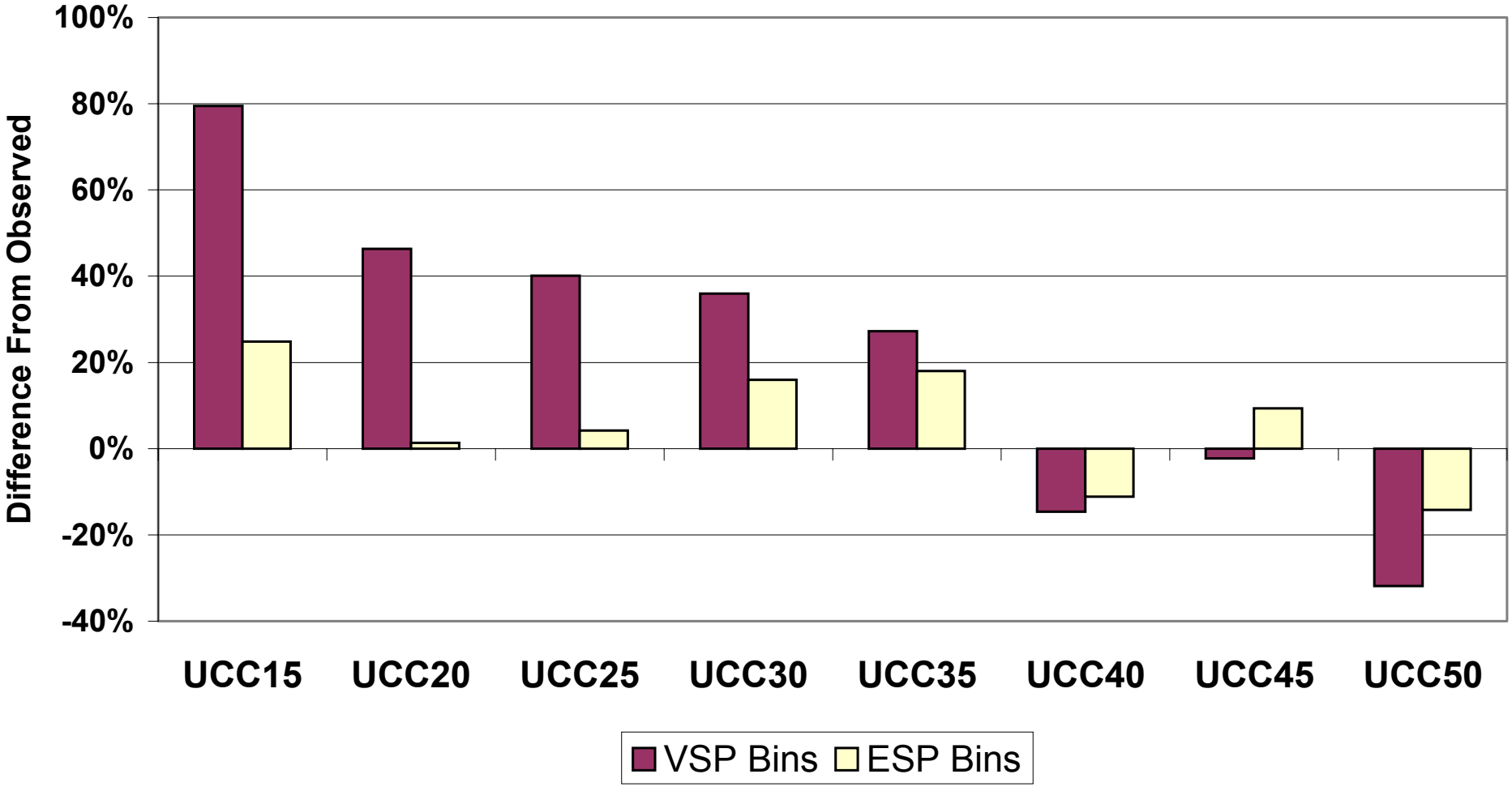
Each Cycle Predicted Independently



NOx Validation: Percent Difference From Observed

ARB UCC Dataset (26 1983-1998 LDV/LDTs)

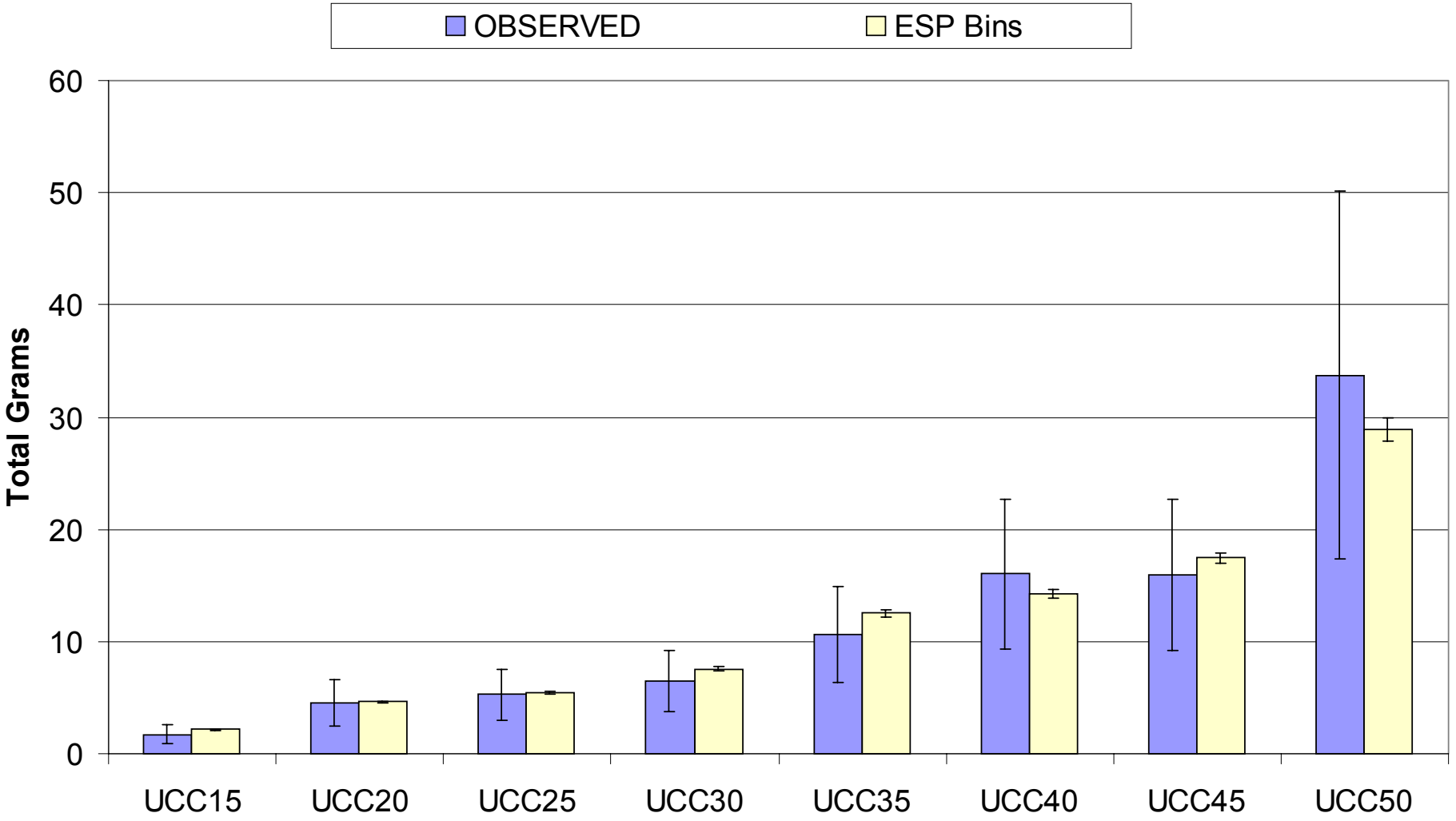
Each Cycle Predicted Independently Based on Binned NOx Emission Rates From The Other 7 Cycles



NOx Validation

Total NOx Per Cycle, Averaged Across Vehicles

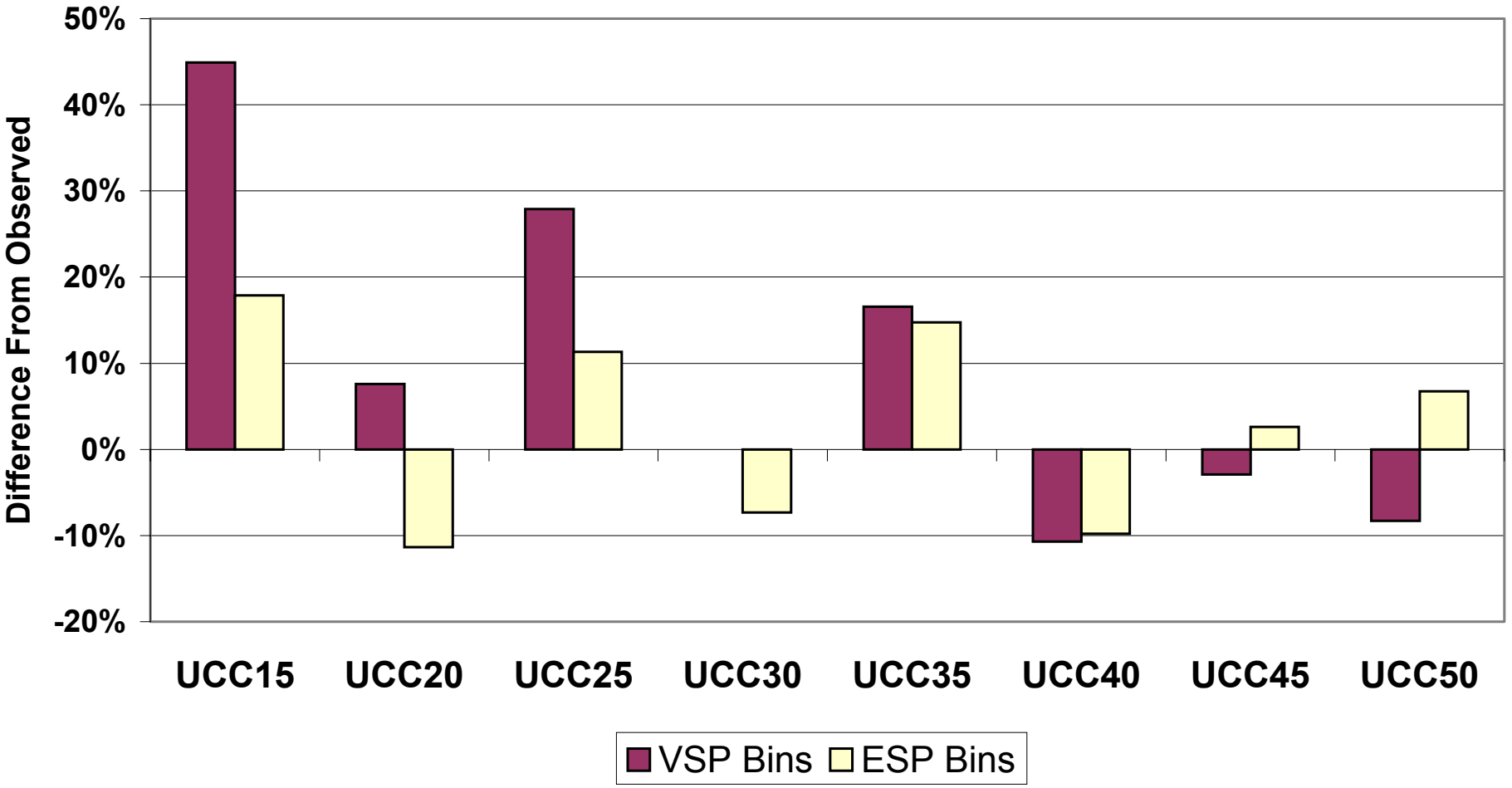
Each Cycle Predicted Independently



CO Validation

ARB UCC Dataset (26 1983-1998 LDV/LDTs)

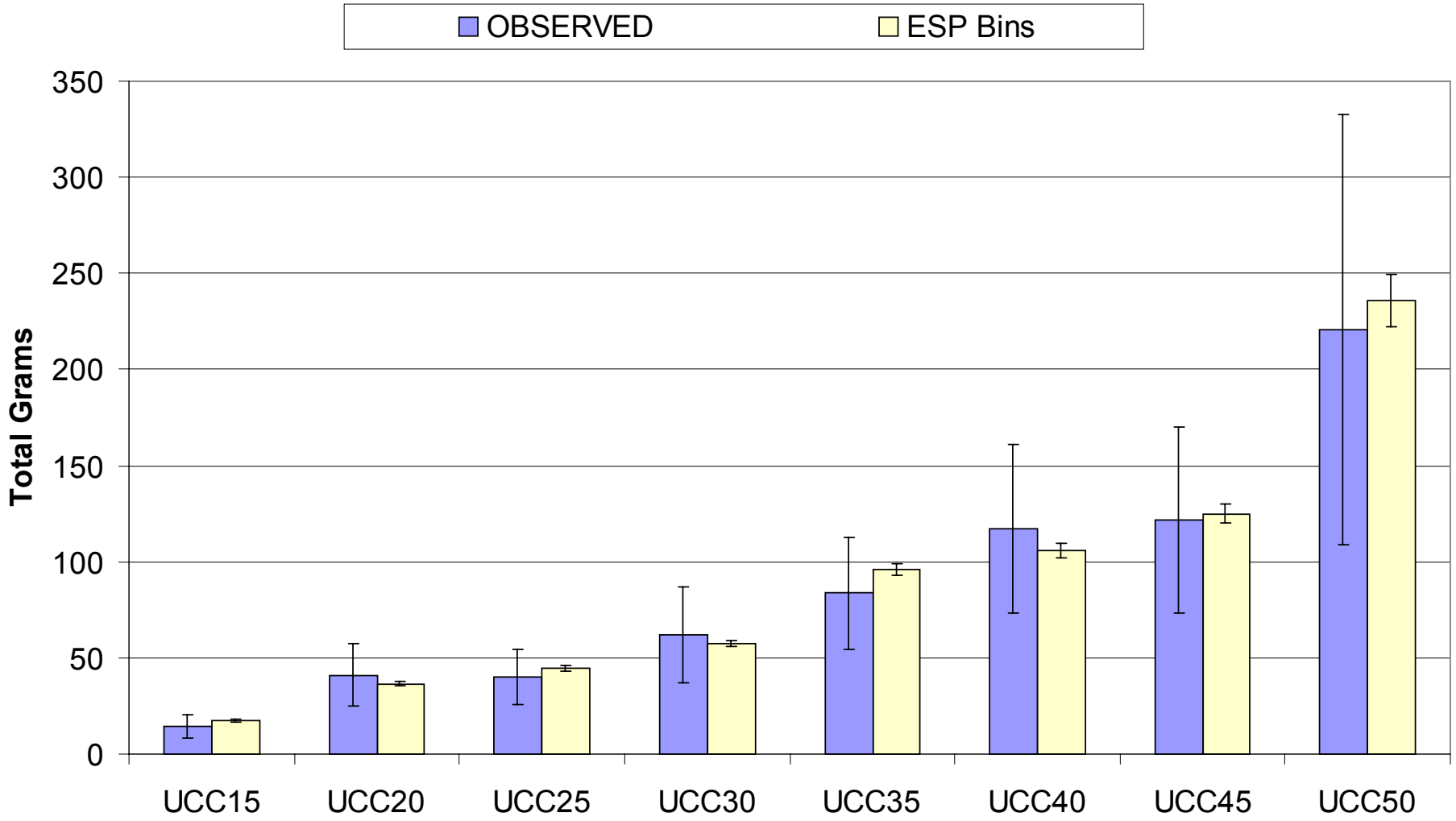
Each Cycle Predicted Independently Based on Binned CO Emission Rates From The Other 7 Cycles



CO Validation

Total CO Per Cycle, Averaged Across Vehicles

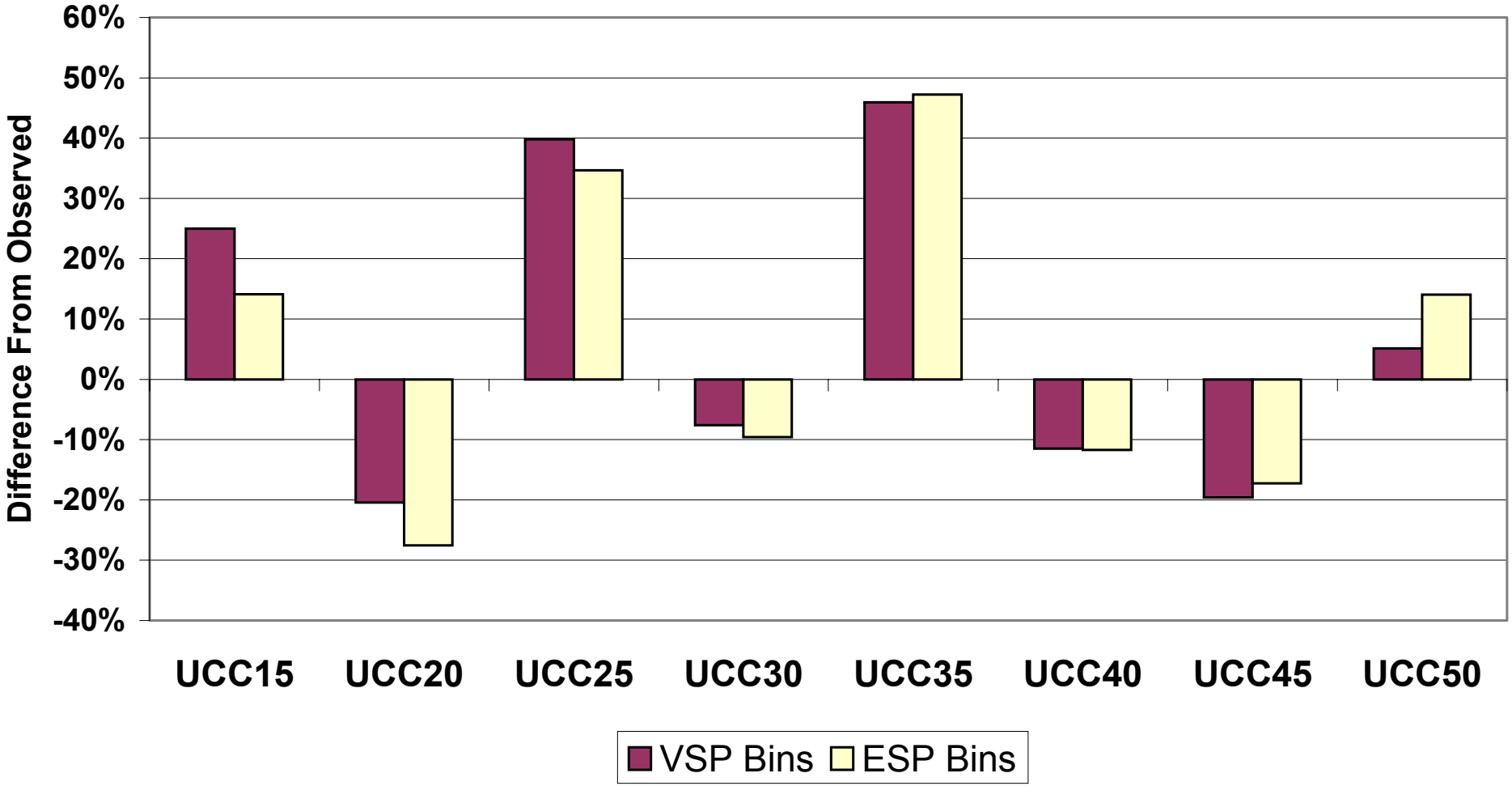
Each Cycle Predicted Independently



HC Validation

ARB UCC Dataset (26 1983-1998 LDV/LDTs)

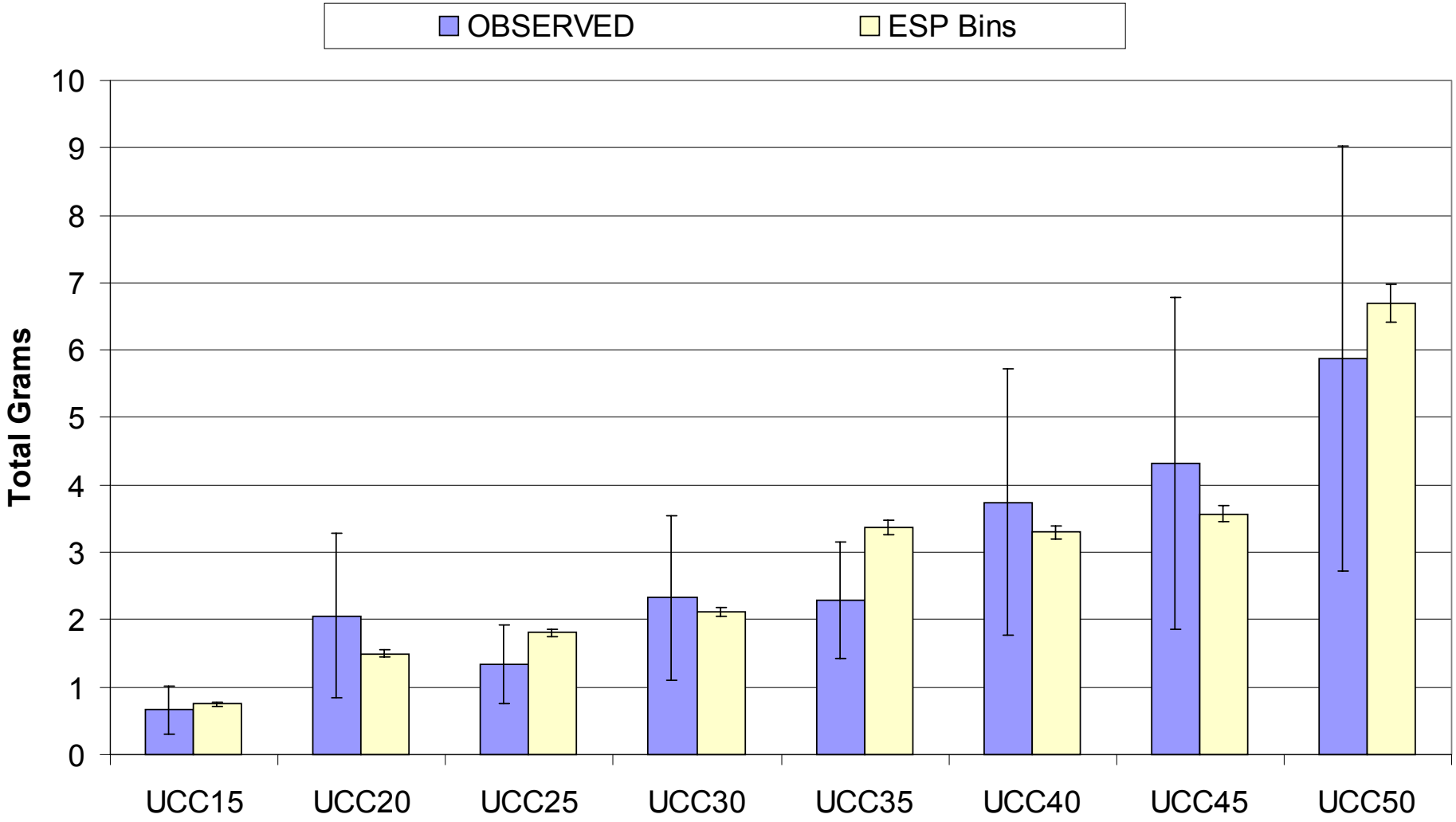
Each Cycle Predicted Independently Based on Binned HC Emission Rates From The Other 7 Cycles

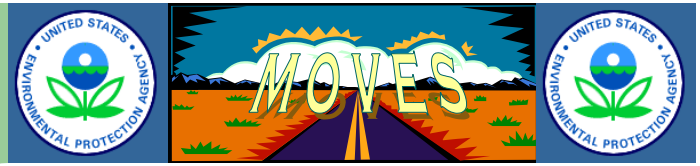


HC Validation

Total HC Per Cycle, Averaged Across Vehicles

Each Cycle Predicted Independently





Proposed Method For Populating Emission Rate Database

- **Empirical binning analysis where representative sample exists**
- **Use PERE to fill data "holes"**
  - Advanced technology vehicles
  - Few data points
  - PERE calibrated using empirical data for "nearest" bin

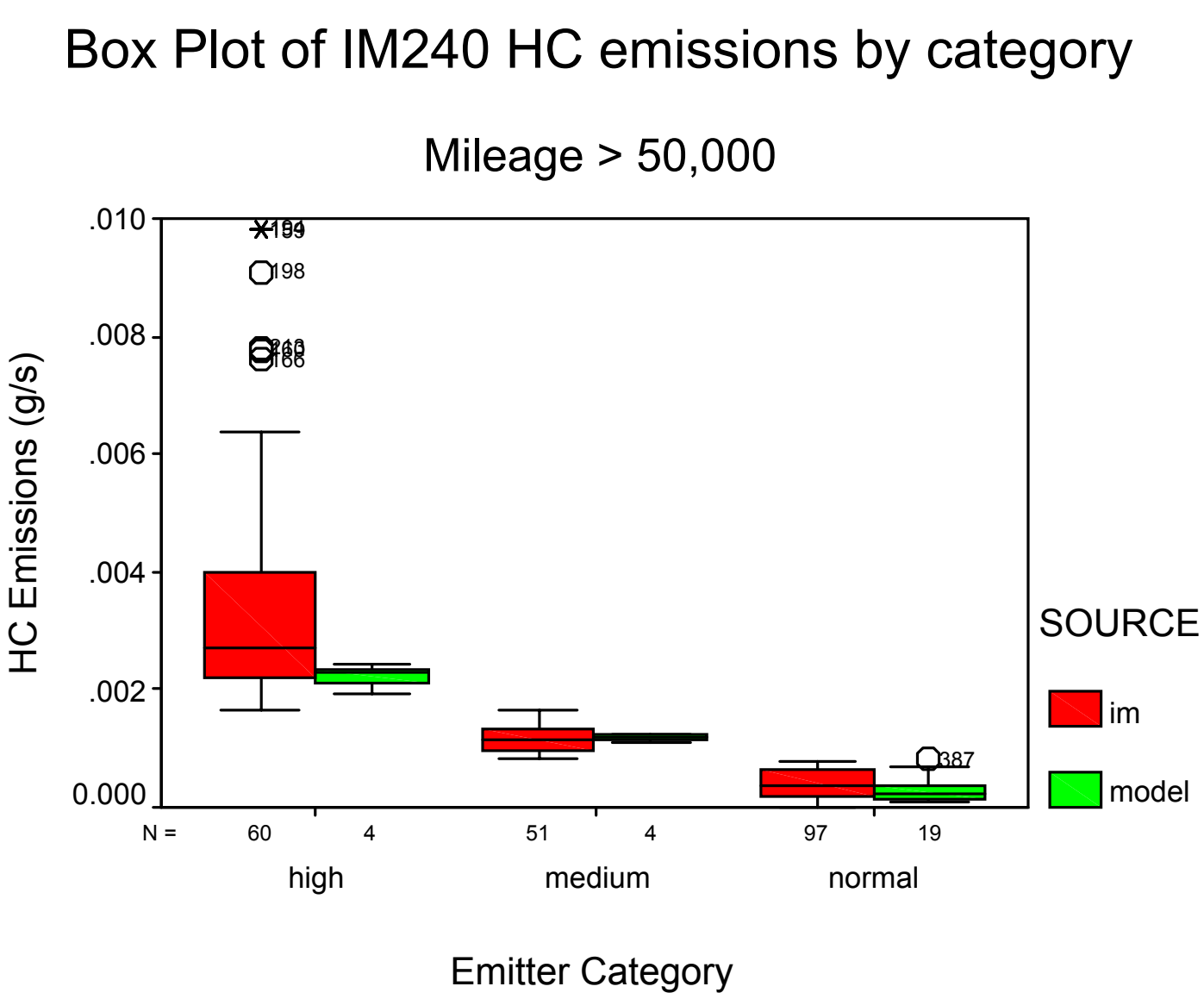
Data To Be Used in MOVES GHG

- **Fuel consumption/emissions**
  - EPA Mobile Source Observation Database
  - Adding additional programs:
    - CARB
    - CRC E-55
    - UC Riverside (CMEM, Heavy-Duty Trailer, Other Studies)
    - Environment Canada
    - WVU (Thousands of heavy-duty chassis tests)
    - Other state and university programs
  - Initial PEMS work (Shootout)
- **Fleet characterization (e.g. populations)**
  - Polk, VIUS
- **Activity characterization (e.g. VMT, driving patterns)**
  - HPMS, NPTS, VIUS, light-duty and heavy-duty driving studies

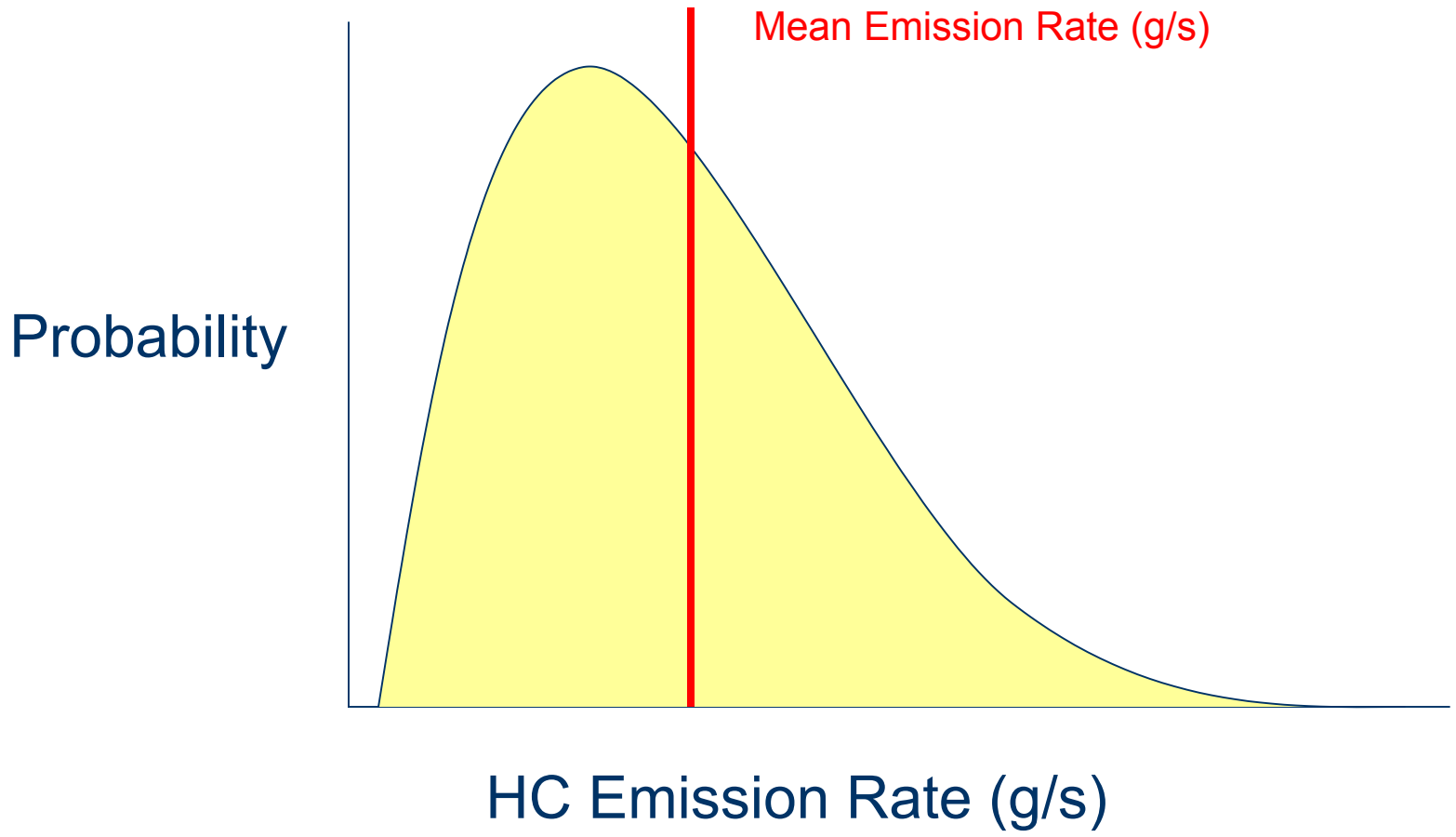
Representing High Emitters

- **Not an issue for MOVES GHG**
  - Floating some initial proposals looking ahead to full implementation
  - More detail in Emission Analysis Plan
- **Traditional Approach**
  - Discrete emitter categories (e.g. “high” & “normal”)
  - Emission level = average within each category
  - Category weightings based on age
- **Proposed MOVES Approach**
  - Emissions expressed as parametric distributions instead of averages
  - Several options for implementing this

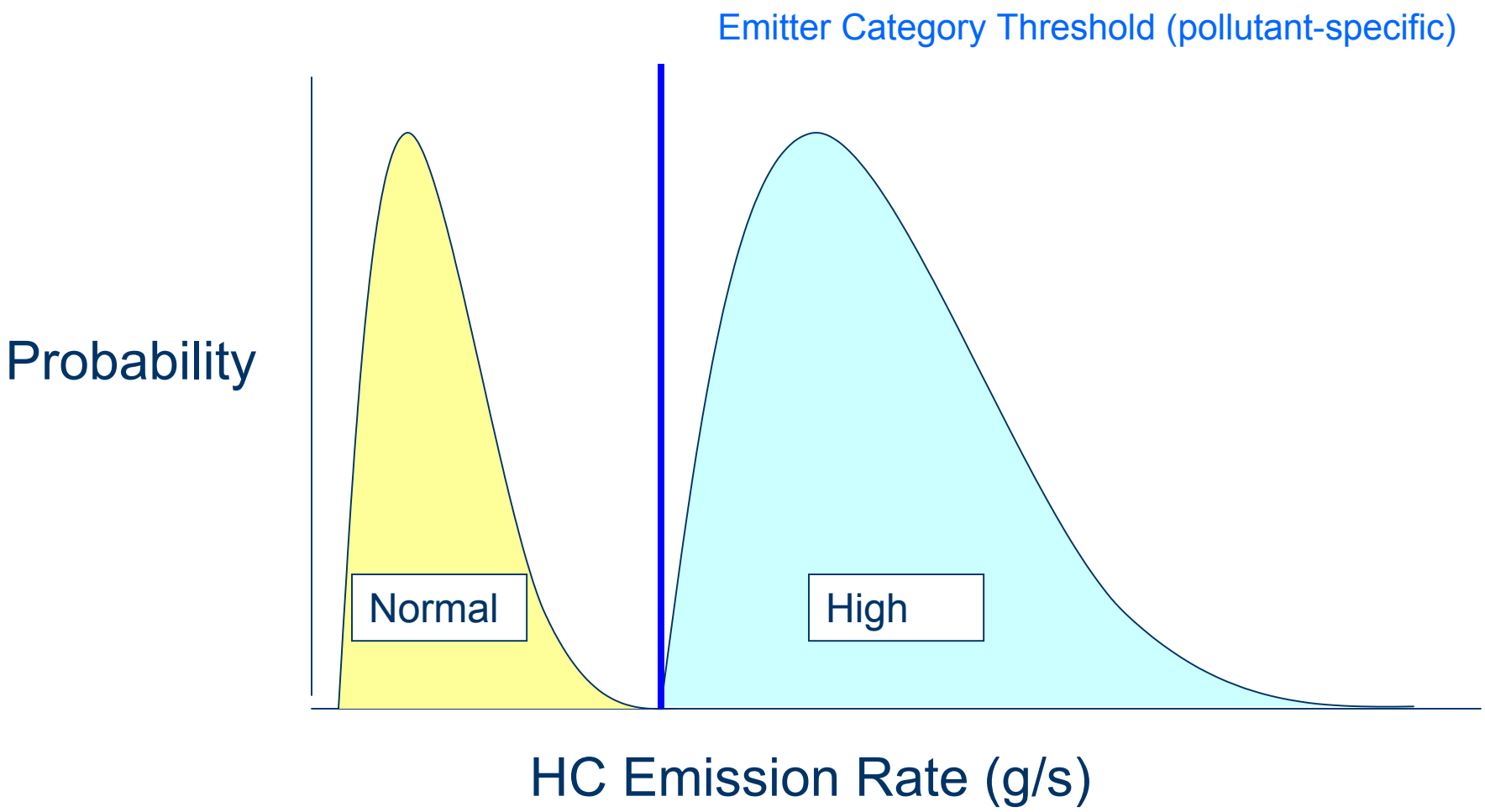
Why Distributions Matter



Single Distribution Illustration

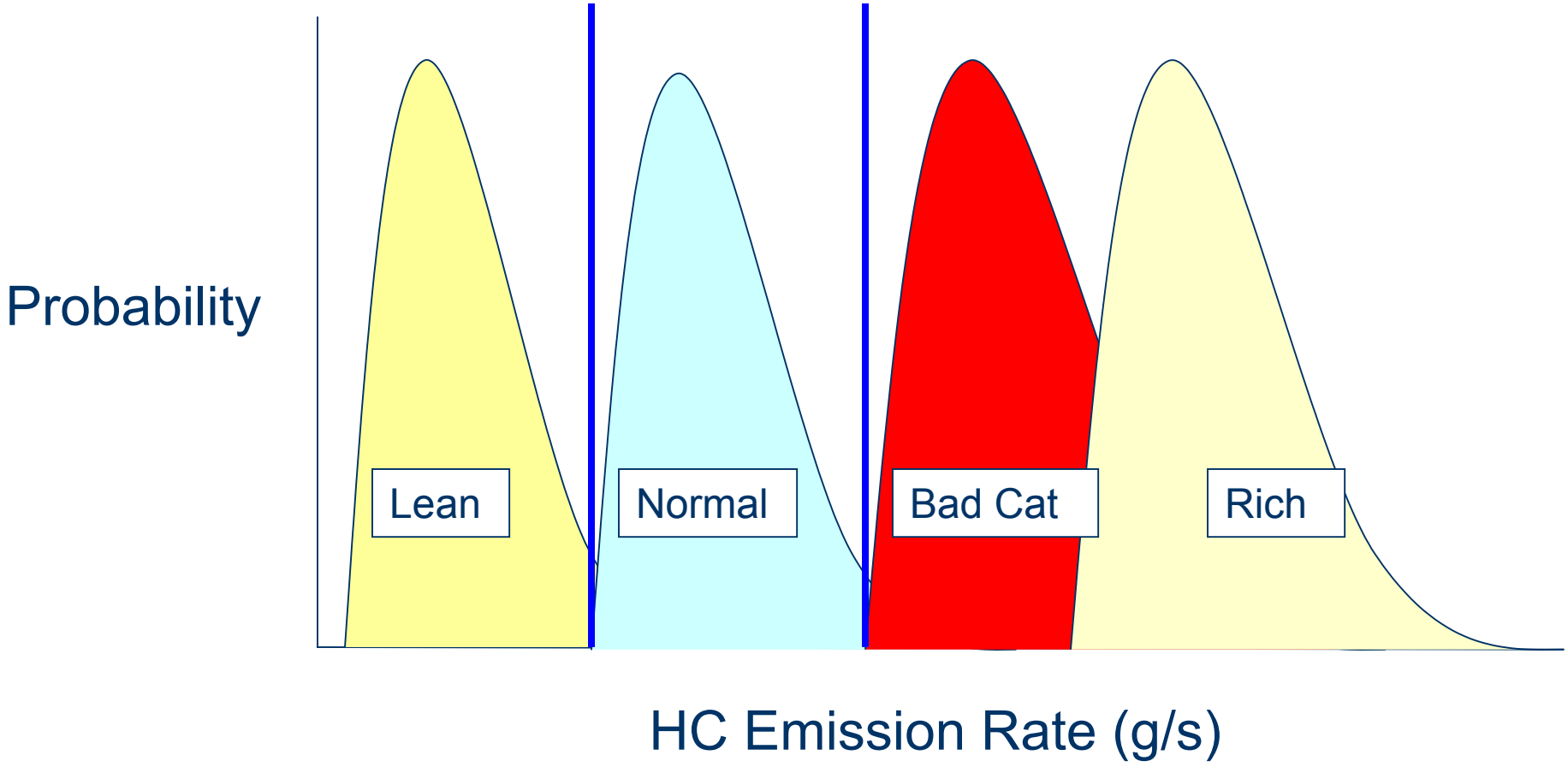


Emitter Category Illustration

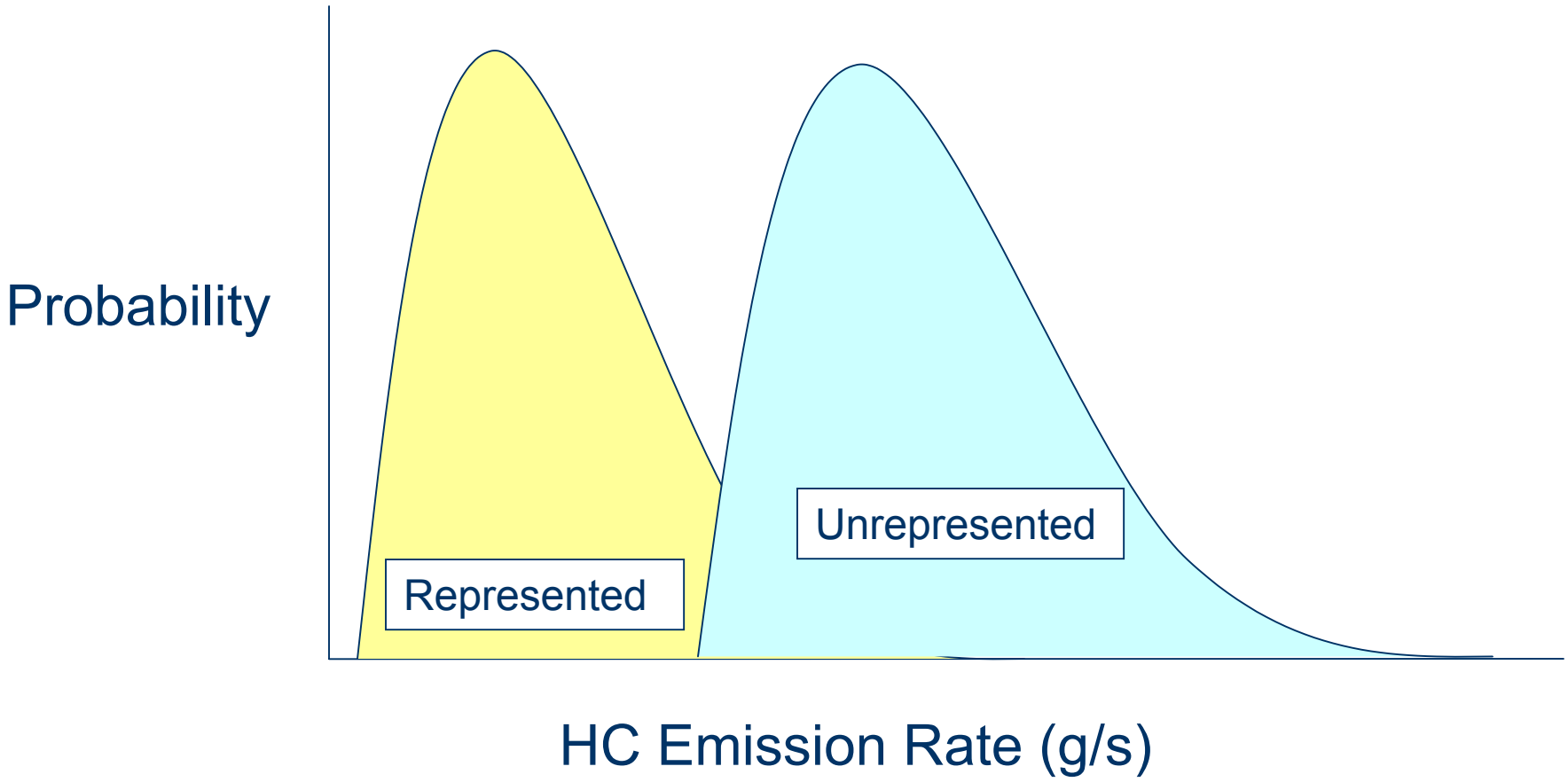


Malfunction Category Illustration

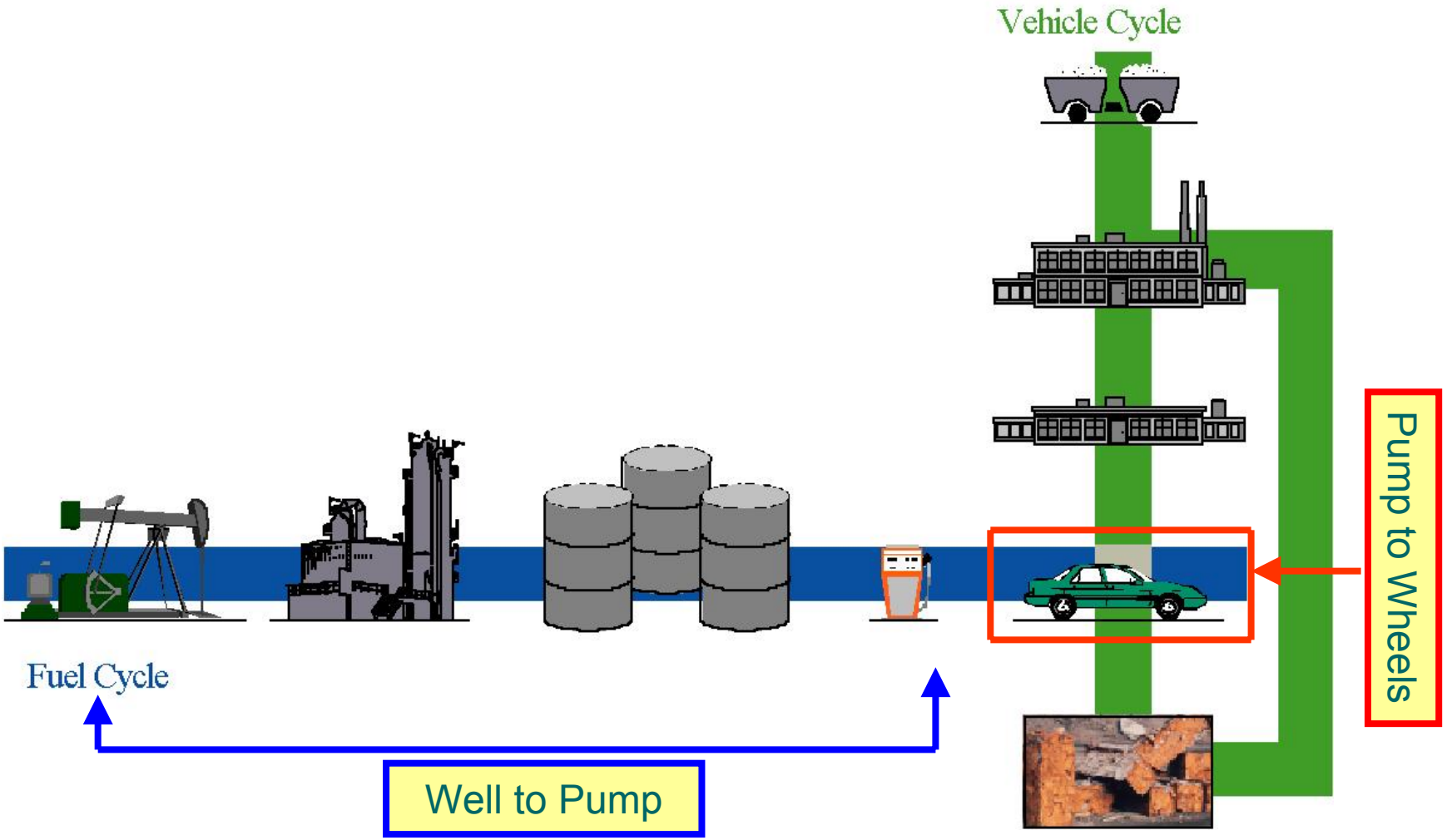
Malfunction Category Thresholds (defined across multiple pollutants)



Unrepresented Category Illustration



Life Cycle – The Big Picture

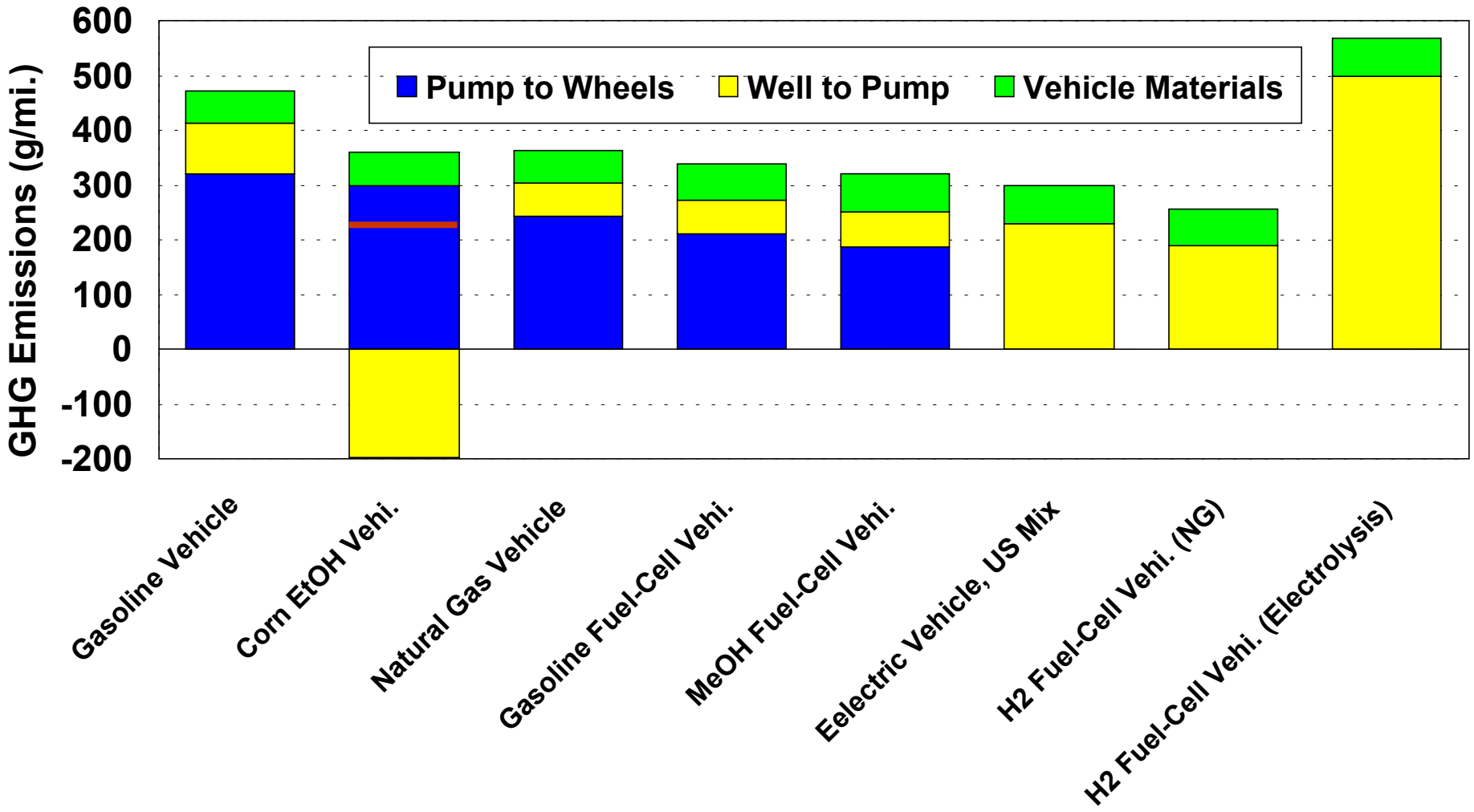


Source: Argonne National Lab

Life Cycle Analysis In A Nutshell

Source: Adrian Raeside

Accounting for Life Cycle Important



Source: GREET, Argonne National Lab

Next Steps for Development of MOVES GHG Fuel/Emission Rates

- **Peer Review and finalization of MOVES GHG Emission Analysis Plan**
- **Complete data gathering and MSOD upload**
- **Continued refinement of ESP binning approach**
- **Develop emission rate tools**
  - "Binning" utility (data crank) for empirical analysis
  - PERE for filling data holes
- **N_2O, CH_4, Starts, Fuels, Temperature, A/C analysis**
- **Populate MOVES Emission Rate Database**
- **GREET integration for life cycle analysis**